Prioritized Technology: Low Temperature Actuators and Mechanisms
Summary of Lubrication, Bearings, Test Facility, and Actuator

Technical Goal

1. Advanced dry lubricant materials that can survive -240˚C to 125˚C temperature cycling and operate at -240˚C
2. Lubrication materials that do not require lubricants such as bulk metallic glasses
3. Bearings innovative approaches that use either gas, liquid, magnetic, dry lubricant or lubricant free approaches such as bulk metallic glass that can survive -240˚C to 125˚C temperature cycling and operate at -240˚C
4. Actuators that push performance of actuators to operate at -240˚C and exploit potential of sensorless commutation and that can survive -240˚C to 125 ˚C temperature cycling, operates at -240˚C and radiation tolerant to total ionizing dose (TID) = 300 krad (Si)
5. Testing facilities that can simulate Titan's lake using liquid methane ("wet " environments) are practically non existents
6. A survey of commercial cryogenic technologies to mature and adapt these technologies for low temperature space flight use.

Technical Status

Many of the current technology can survive -190˚C, but for very short time or few cycles.

1. Lubricants: Dry lubricants (e.g. PGM-HT, sputtered MoS2) and non lubricated systems (e.g. bulk metallic glass (BMG) developed but further testing is needed to define their LT capabilities
2. Bearings: Many bearing types under development (gas, liquid, active magnetic, permanent magnet) as well as non-lubricated bearings (e.g. BMG) are at various stages of readiness
3. Actuators: Piezoelectric, brushless actuators at -190˚C currently operational – shaft sensors are evolving rapidly. Eg. JWST 1-time deployable actuators were tested to -190C
4. Testing: Testing capabilities are limited. JPL has a liquid methane bath but facility needs maturing for component testing

Mission Applications

1. Europa [Near Term] robotic arm, gimballed antenna and camera requires a range of capabilities (lubrication, bearings, actuators and gearboxes).
2. Titan landers [Mid/Far term] pin point landing enabled. If capability realized, mission duration will be extended
3. Ice penetration and sampling on Ocean Worlds in the Mid/Far Term on missions would be extended from a couple weeks to few months.
4. Enabling this low temperature technology will allow us to reduce mass, power consumption (no heaters), and thermal losses (less cables) which ultimately, extends mission life. If actuators need not need heaters to operate, more power would be available for instrument operation and would extend the mission life. e.g. M2020, it could take up to 3 hours with energy as high as ~400Wh in order to warm up one of the arm actuators from -100C to -30C. Having actuators that operate at -240 would save energy and warm up time, which would increase science operating time and extend mission life. Thermal leaks will be reduced with no heater, PRT and control cables. The heat loss for a 1 meter 20AWG copper that links cold sink at -240˚C to hot source at 10KC is ~0.2W. Reducing the number of wire from 20 wires to 10, would save about 2W power. Fewer heaters also help reduce thermal contamination of the area of interest. Although heaters, PRTs, and thermostat are low mass, savings from no MLI could be considerable as the typical A142 20-layer MLI is 1kg/m2. Required MLI is highly dependent mission architecture but baseline area for MSL type mission is about 3-4 m2.
5. Another improvement very much needed is to increase target lifetime low temp cycles of operation from 500-1000 cycles to a few million cycles for the actuators. For Mars2020, the requirement for MOXIE is to run 3000rpm for 10 hours; translating to about 4 million cycles testing needed (2X life). In addition, percussion actuators requirement is 25Hz for 30 hours (or 5.4 million cycles if tested at 2X life).
6. Enabling these lower temperature technologies will enable science in Europa, Titan, and other ocean worlds.